PNE-510F

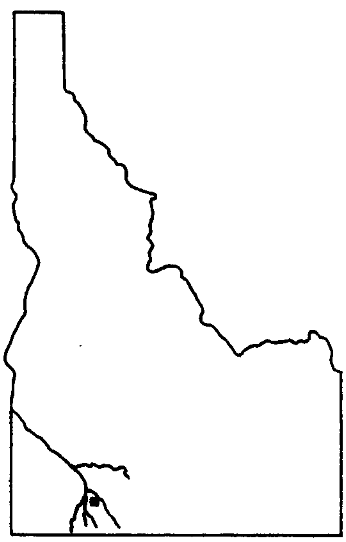
C. 2

PNE - 510F

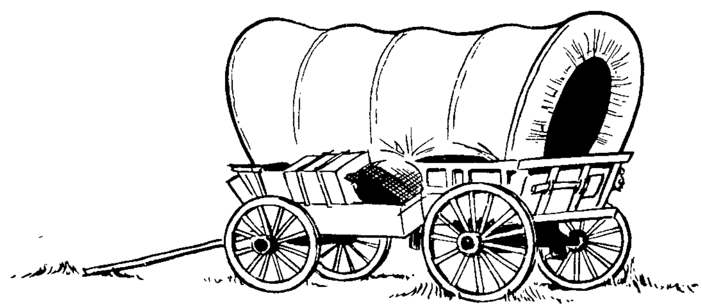
Plowshare civil, industrial and scientific uses for nuclear explosives

UNITED STATES ARMY CORPS OF ENGINEERS

BRUNEAU PLATEAU, IDAHO
30 September 1965



PROJECT PRE-SCHOONER II



DESIGN, CONSTRUCTION, AND POSTSHOT EVALUATION OF CONCRETE STEM FOR ACCESS HOLE

KENNETH L. SAUCIER, PROJECT OFFICER
F. S. STEWART
U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

U.S. Army Engineer Nuclear Cratering Group
Livermore, California

ISSUED: August 1967

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U. S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

PROJECT PRE-SCHOONER II

PNE-510-F

DESIGN, CONSTRUCTION, AND POSTSHOT EVALUATION OF CONCRETE STEM FOR ACCESS HOLE

Kenneth L. Saucier, Project Officer
F. S. Stewart

U. S. Army Engineer Waterways Experiment Station
Corps of Engineers
Vicksburg, Mississippi

May 1967

ABSTRACT

Project Pre-Schooner II consisted of a 100-ton chemical explosive detonated in hard, dry rock at a depth of 71 feet. The primary purpose of the project was to increase the knowledge of crater dimensions in hard, dry rock as a function of depth of burst and type of explosive. This report describes the proportioning of a concrete mixture used in stemming the access hole of the shot cavity, the design of the stem configuration, laboratory tests conducted on core samples from the site and on specimens of the concrete mixture required for design of the stem, and placement of the concrete at the job site. Based on observations of the detonation, fractured pieces of the reinforced concrete stem, and the size of the crater, it is believed that the stem acted effectively to stem the detonation.

PREFACE

The work described in this report was authorized by MIPR No. NCG1AO 8-65, Change No. 1, dated 12 May 1965, from the U. S. Army Engineer Nuclear Cratering Group, Livermore, California, to the U. S. Army Engineer Waterways Experiment Station (WES).

The work was performed at the WES Concrete Division and the Bruneau Plateau region of southwestern Idaho under the supervision of Mr. Bryant Mather, Chief, WES Concrete Division, and Messrs. James M. Polatty, William O. Tynes, and Kenneth L. Saucier, Project Officer. This report was prepared by Messrs. Saucier and Frank S. Stewart.

Director of the WES during the conduct of this investigation and preparation of this report was COL John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

CONTENTS

FIGURES

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	25.4	millimeters
square inches	6.4516	square centimeters
feet	0.3048	meters
miles	1.609344	kilometers
cubic feet	0.0283168	cubic meters
cubic yards	0.764555	cubic meters
pounds	0.45359237	kilograms
tons	907.185	kilograms
pounds per square inch	0.070307	kilograms per square centimeter

PROJECT PRE-SCHOONER II

DESIGN, CONSTRUCTION, AND POSTSHOT EVALUATION OF CONCRETE STEM FOR ACCESS HOLE

INTRODUCTION

DESCRIPTION OF PRE-SCHOONER II SHOT

Project Pre-Schooner II was a chemical explosive single-charge cratering experiment in hard, dry rhyolite rock executed by the U. S. Army Engineer Nuclear Cratering Group as a part of the joint Atomic Energy Commission-Corps of Engineers nuclear excavation research program. Pre-Schooner II was detonated on 30 September 1965 about 5:10 p.m. (Mountain Standard Time) on Bruneau Plateau, approximately 40 miles[1] southwest of Bruneau, Idaho. The emplacement hole was at the following coordinates: long. 115°34'25.203"W, lat. 42°24'02.943"N (Modified Idaho State Coordinate System - N 267,639.53; E 547,783.11). The cavity, located at a depth of 71 feet, contained approximately 85.5 tons of nitromethane (CH_3NO_2) at zero time. The detonation resulted in a crater with an apparent crater radius of 95.2 feet, an apparent crater depth of 60.7 feet, and an apparent crater volume of 24,780 yd^3.

1 A table of factors for converting British units of measurement to metric units is presented on page 7.

OBJECTIVES

The objective of the laboratory phase of the investigation described herein was to design a concrete stem for the access hole that would replace the in situ material in such a manner that the crater would develop as if an access hole had not been drilled. The objectives of the fieldwork were to construct the stem in place, observe the detonation, and evaluate the effectiveness of the stem.

BACKGROUND

The cratering data from the Buckboard and Pre-Schooner I series of 20-ton, high-explosive experiments and the Danny Boy and Sulky nuclear-explosive experiments exhibit considerable scatter. Because of this scatter, it is difficult to predict with confidence the apparent crater dimensions as a function of depth of burst in hard, dry rock. It was hoped that the results of Pre-Schooner II would reduce the uncertainties in predicting apparent crater dimensions in hard, dry rock in the region of optimum depth of burst, and serve as a correlation shot for the Schooner event.

THEORY

In order to prevent the energy of an explosion from venting prematurely through the access hole, the access hole must be adequately stemmed with a material that will react in the same manner as the in situ medium when subjected to the forces of the detonation. A

reinforced concrete stem, utilizing shear keys if necessary, was considered to be the most practical design for this purpose (see Figure 1).

The basic criterion was to design the total bond-shear resistance of the concrete-felsite interface to be at least equal to the total unconfined, static shear resistance of the felsite by using bond-shear strength of concrete to felsite and shear keys as necessary. The resistance capacity of the stem was considered separately in each stratum of felsite. Shear keys, if required, could be designed from a dynamic approach, since literature on this particular subject is available.

Other pertinent criteria were as follows:

1. The 21-day strength of the concrete design proportioned at the U. S. Army Engineer Waterways Experiment Station (WES) and cured under optimum conditions in the laboratory was to be reduced 15 percent for design calculations because of unknown field curing conditions and the uncertainty of the detonation schedule.

2. For ease of mining, the key was to be of the "dovetail" type, designed shoulder down, with a convenient ratio of key shoulder size to key height.

3. There was no requirement for vertical steel in this design approach.

PROCEDURE

EXPERIMENTAL PLAN

The stemming material was to be a concrete mixture proportioned to match as closely as possible the structural properties of the in situ material. Core samples taken from the jobsite were to be shipped to the laboratory for testing. The test results were to be used to design the stem configuration. The concrete would be placed in the shot hole using recommended procedures and allowed to cure. Observation of the detonation, crater, and pieces of fractured stem would assist in evaluating the effectiveness of the stem.

Considering the structural properties, it was obvious that the continuous medium would not react in the same manner as the laboratory specimens. The standard tests for tensile, shear, and compressive strengths are unconfined tests on specimens extracted from the continuous medium. Thus, in reality, the application of unconfined test values in lieu of confined test values is only an approximation. Nevertheless, it was deemed appropriate to use this approach due to the many unpredictable and uncertain facets inherent in cratering phenomena today and the practical limitations on an extensive design study.

CONCRETE MIXTURE USED FOR STEMMING

The concrete mixture for use in the stemming was proportioned to

have a cement factor of 7.5 bags/yd^3, a water-cement ratio of 0.46 by weight, and a slump of 3-1/2 $\pm$ 1/2 inch. The mixture proportions are presented in the following tabulation.

BATCH DATA BASED ON ONE BAG OF CEMENT

Materials	Solid Volume	Saturated Surface-Dry Weight
	yd^3	lb
Type III portland cement	0.479	94.00
Metallic aggregate	0.085	30.00
Crushed natural sand	0.820	132.30
Crushed natural coarse aggregate	1.522	247.60
Water	0.694	43.24
Concrete coloring	--	5.00
Water-reducing admixture (lignin base)	--	0.25

At each quarter height of the stem the concrete coloring was to be changed to aid in the postshot study of crater ejecta. The metallic aggregate, a commercial product consisting primarily of iron filings, was used to increase the density and prevent shrinkage of the mixture. The coarse aggregate was nominal 1-1/4-inch maximum size, crushed natural chert. The grading of each of the aggregates except the metallic was as follows:

Sieve Size	Cumulative Percent Passing	
	Coarse Aggregate	Fine Aggregate
1-1/2-inch	100.0	--
1-inch	97.1	--
3/4-inch	77.7	--
1/2-inch	41.2	--
3/8-inch	21.0	100.0
No. 4	1.9	99.0
No. 8	--	85.6
No. 16	--	65.5
No. 30	--	34.5
No. 50	--	11.3
No. 100	--	4.5
No. 200	--	1.8

The specific gravities of the coarse and fine aggregates were 2.61 and 2.59, respectively; the percentage of absorption was 1.2 for both aggregates.

LABORATORY TESTS OF CONCRETE AND FELSITE

Bond-shear, tensile, and compressive-strength tests were conducted on the concrete to obtain data for comparison with the properties of the felsite at the test site. A description of these tests follows.

The purpose of the bond-shear or punch-out tests was to simulate, on a small scale, the effect of the blast on the concrete stem. Six-inch-diameter cores obtained from the test site were sawed into

lengths ranging from 3 to 12 inches. These specimens were then grouted into a square form to furnish stability during the drilling of a 3-inch-diameter hole through the center of each specimen. The holes in the specimen were then filled to different depths with the stem concrete mixture, which was allowed to cure for 7 days. In each specimen, the top end of the concrete "plug" was capped with a high-strength gypsum compound. A typical specimen is shown in Figure 2. Each specimen was placed and grouted in a stabilizing frame with the high-strength gypsum plaster to produce a condition of biaxial confinement. The frame was placed in a 440,000-pound-capacity testing machine; a 3-inch-diameter steel piston was placed on the capped concrete plug, and the entire assembly was carefully leveled to avoid eccentric loading. The piston was loaded (Figure 3) until the bond between the concrete and felsite failed.

Dynamic tensile-splitting strength (σ_t) and compressive strength (σ_c) tests were performed on the felsite and stemming concrete to obtain data for use in the design analysis and to compute shear strength. The shear values (c) used in the calculation were obtained from the dynamic compressive and tensile strength values plotted on a Mohr's circle. The shear strength analysis is presented in Figure 4 (Reference 1).

RESULTS

ACCESS HOLE GEOLOGY

The geologic condition of the Pre-Schooner II site was as follows:

Depth feet	Description
0-7	Residual soil
7-40	Layers of felsitic vitrophyre, volcanic breccia, and fractured porphyritic felsite
40-62	Porphyritic felsite, hard dense, some areas highly fractured

LABORATORY TESTS OF CONCRETE AND FELSITE

The averages of the results of the various tests are given below:

Test Property	Felsitic Vitrophyre	Porphyritic Felsite	Concrete
Punch-out (bond-shear) strength, psi	2,230	1,950	--
Dynamic compressive strength, σ_c (unconfined), psi	5,860	18,800	--
Dynamic tensile splitting strength, σ_t (unconfined), psi	715	1,675	--
Dynamic shear strength, C (computed), psi	1,010	2,770	--
Static compressive strength, f'_c, psi	--	--	6,700

Note: The concrete in the punch-out tests had been cured for 7 days. The concrete in the strength tests had been cured for 21 days.

STEM DESIGN

APPROACH

The initial assumption indicated that to prevent the stem from blowing out before the felsite at the time of blast, there had to be at least as much shearing resistance between the stem and the in situ felsite as there was in the felsite. It was evident from the punch-out test results that the bond-shear value was greater than the shear strength for felsitic vitrophyre, but a key would be required to match the shear strength for the 22 feet of felsite. Since the key would be designed to fail with the felsite, ultimate design procedures would apply. Thus, the reinforcing steel and the concrete would act together to achieve ultimate strength (Reference 2).

The design procedure for matching the shear resistance in the felsite region was as follows.

1. Compute the shear resistance of the felsite mass based on the circumferential surface of the access hole.

2. Assume a key size, and compute the available concrete bond-shear resistance of the access hole circumferential area less the key height and the 3-foot "dead space" above the sphere, which will contain instrumentation.

3. Compute the shear resistance required to match the felsite (computation 1 minus computation 2).

4. Compute the dynamic shear resistance of the shear key using the appropriate dimensions and the following expression (Reference 3) for one unreinforced key:

$$\tau = 0.64f'_c$$

where

τ = shear resistance, psi

f'_c = compressive strength of concrete, psi

5. Compute additional shear strength supplied by using reinforcing steel bars and applicable design recommendations for shear strength of steel (21,000 psi is taken from page 9 of Norris and others (Reference 2)).

6. Compute total force available, and check against shear resistance to match the felsite (computation 3).

7. Compute the required length of steel bars to fully develop the dynamic bond on each side of the shearing plane. Norris and others (Reference 2), page 46, recommended an ultimate dynamic bond stress of $0.15f'_c$.

CALCULATIONS

Field logs indicated a stratum of felsite at a depth of 40 to 62 feet. A key was required to match the shear strength for 22 feet of felsite, and the following calculations were used to design the key:

1. Shear resistance of felsite (interface area) = hole circumference (inch) $\times$ shear strength (psi) $\times$ height of felsite region (inch) = $113 \times 2{,}770 \times 22 \times 12 \approx 8.26 \times 10^7$ pounds.

2. To obtain available concrete bond-shear resistance, an 8-foot-high key was assumed; 12 feet of circumferential area was available for bond. Hole circumference (inch) $\times$ bond shear (psi) $\times$ height of felsite region (inch) = $113 \times 1{,}950 \times 12 \times 12 \approx 3.17 \times 10^7$ pounds.

3. A key was needed to provide the additional 5.09×10^7-pound ($8.26 \times 10^7 - 3.17 \times 10^7$) resistance.

4. Unit shear resistance (τ) of a key = $0.64f'_c \times 0.85$. (The strength of the laboratory-proportioned concrete was reduced 15 percent for design calculations because of the uncertainty of field curing conditions.) Hole circumference (inch) $\times$ compressive strength of concrete (psi) $\times$ height of key (inch) = $113 \times 0.64 \times 6{,}700 \times 96 \approx 4.65 \times 10^7$ pound.

5. Ten No. 10 reinforcing steel bars per foot were added to provide additional strength. A double area of 2×1.27 in.^{2} = 2.54 in.^{2}. The dynamic shear strength of steel is taken as 21,000 psi. The doubled diameter (inch) $\times$ shear strength of steel (psi) $\times$ number of bars per foot $\times$ height of key (foot) = $2.54 \times 21{,}000 \times 10 \times 8 \approx 0.43 \times 10^7$ pound.

6. The available force (sum of calculations 2, 4, and 5),

8.25×10^7 pounds, adequately matches the required force (calculation 1).

7. The following procedure was used to determine the required length of steel in the keyway to develop sufficient bond.

(a) f'_c (psi) = $0.85 \times 6{,}700 \approx 5{,}700$.

(b) Bond strength (psi) = $0.15 \times 5{,}700 \approx 860$.

(c) Circumference of No. 10 bar (inch) = 3.99 .

(d) Bond strength per inch of bar length (pound) = $3.99 \times 860 \approx 3{,}430$.

(e) Force developed in each bar (pound) = $21{,}000 \times 1.27 = 26{,}670$.

(f) Length of steel bars required in the keyway to develop sufficient bond = $\frac{26{,}670}{3{,}430} = 7.78$ inches.

An 8-foot-high key with a lip depth of 3.0 feet and ten No. 10 reinforcing steel bars (8-inch minimum bonded length) per foot of key height was recommended.

FIELDWORK

The sphere and key configuration was mined as shown in Figure 1. The reinforcing steel was placed in the key, and the first lift of concrete was placed covering the reinforcing steel. The second lift, placed 24 hours later, brought the stem to the ground surface. The concrete was colored with various colors at different depths, as

shown below, to aid in postshot identification of recovered pieces of stem.

Lift	Color	Depth Intervals feet
1	Yellow	Top of sphere to 52
2	Green	52 to 43
2	Brown	43 to 20
2	Terra-cotta	20 to ground surface

POSTSHOT RESULTS

LABORATORY TESTS OF CONCRETE

Field-cast specimens from the reinforced concrete stem, 6- by 12-inch cylinders, were sent to the WES where they were tested on the detonation date. The specimens were 21 days old at time of test. Results are given below. The static strength results (approximately 9,000 psi) are indicative of high-quality concrete and undoubtedly resulted in higher bond and shear strengths than those used in the stem design (see page 18). To gain some knowledge of the impact properties of the concrete, dynamic compressive strength tests were conducted on several specimens. Rise time was approximately 1 msec. As shown in the following tabulation, the dynamic strength of the concrete was approximately 25 percent greater than the static strength.

Depth Interval	Color of Concrete	Stem Portion	Static Compressive Strength,[a] 21-Day Age	Dynamic Compressive Strength,[b] 21-Day Age
feet			psi	psi
62 to 52	Yellow	Lower key	8,670	10,870
52 to 43	Green	Upper key	8,510	11,500
43 to 20	Brown	Midstem	9,370	11,720
20 to 0	Terra-cotta	Top stem	9,120	11,050
		Average	8,920	11,280

[a] Each value is the average of four tests.
[b] Each value represents one test.

FIELD SURVEY

Sliding and sloughing of the sides prevented entry into the crater proper, and a thick covering of dust severely hampered the search for pieces of the concrete stem. Several small pieces of green and yellow concrete, none larger than 1 ft^3, indicated that high compressive forces had acted on the lower stem as expected. These pieces were highly fractured, through both the mortar and the aggregate. Three small pieces of reinforcing steel, the largest approximately 1 foot long, were located at various distances from the crater rim. The broken steel gave evidence of large shearing forces although the concrete had been stripped from the steel. No pieces

of concrete stem from the upper sections, color-coded brown and terra-cotta, were located.

CONCLUSIONS

Based on visual observations of the detonation and of fractured pieces of the reinforced concrete stem, the stem effectively contained the shot as no evidence of "blowout" was detected. The dimensions of the apparent crater (95-foot radius, 60-foot depth), when compared to the predicted dimensions (75-foot radius, 40-foot depth), also indicated an effective stem.

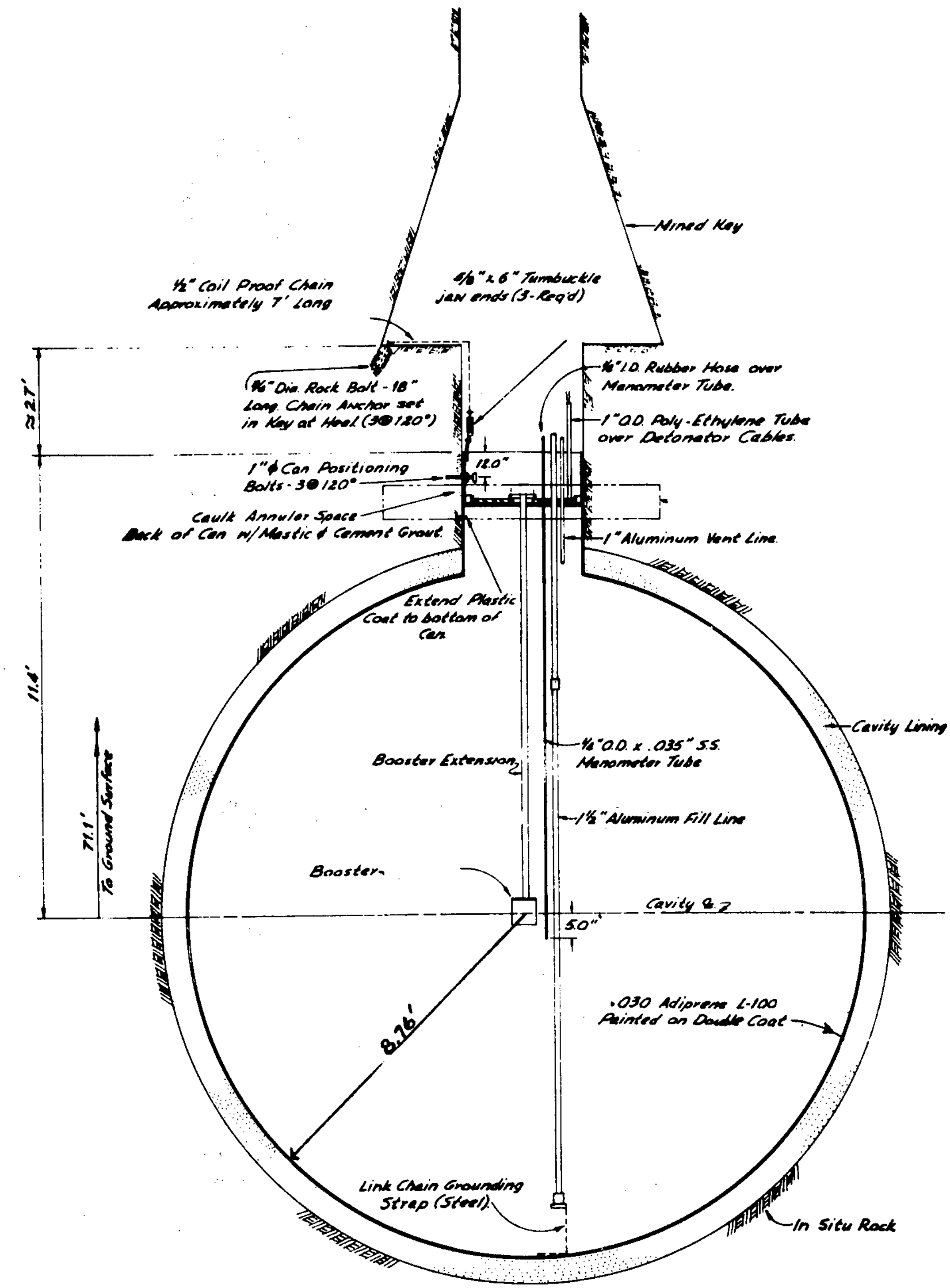
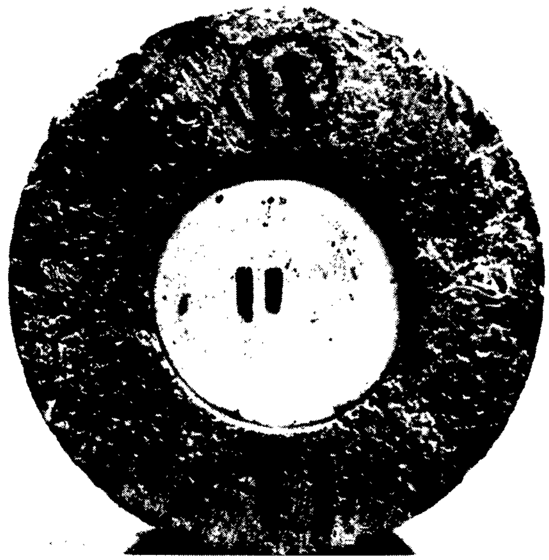
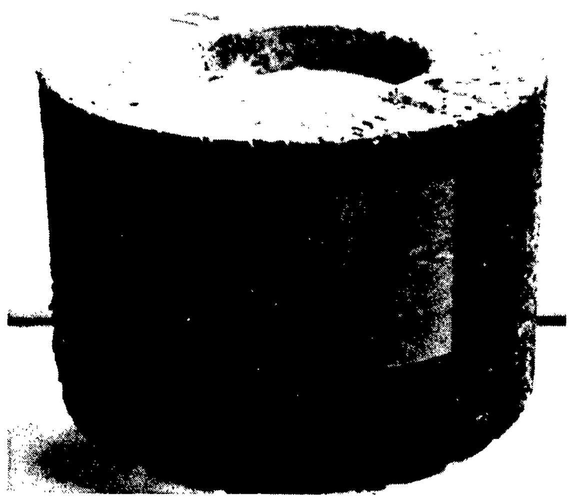


Figure 1 Cross section of Pre-Schooner II chemical-explosive charge.



a. Top view showing high-strength gypsum plaster cap on concrete filler.



b. Side view (3-5/16 inches corresponds to the height of concrete filler from the base to the cap).

Figure 2 Punch-out test specimen with concrete filler in place.

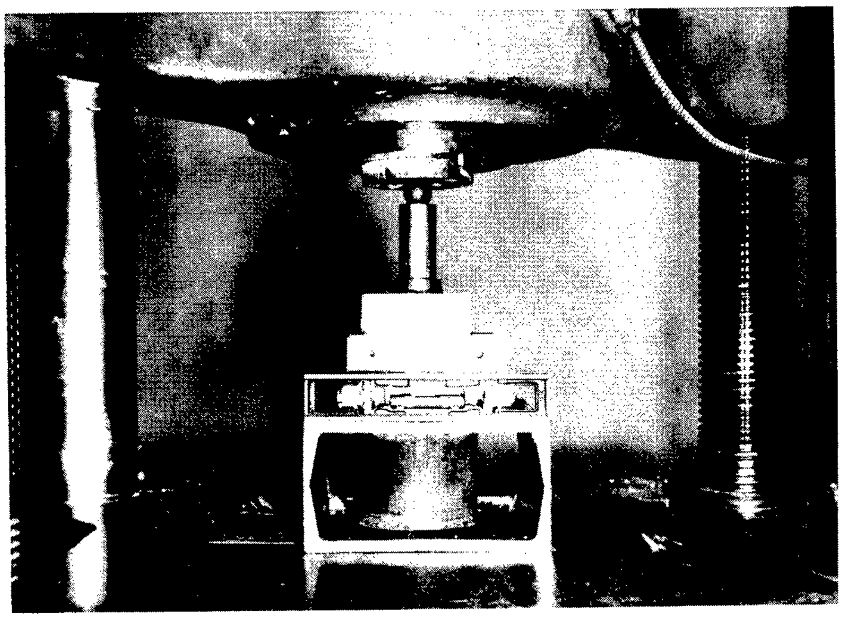


Figure 3 Loading apparatus for punch-out tests with specimen in place.

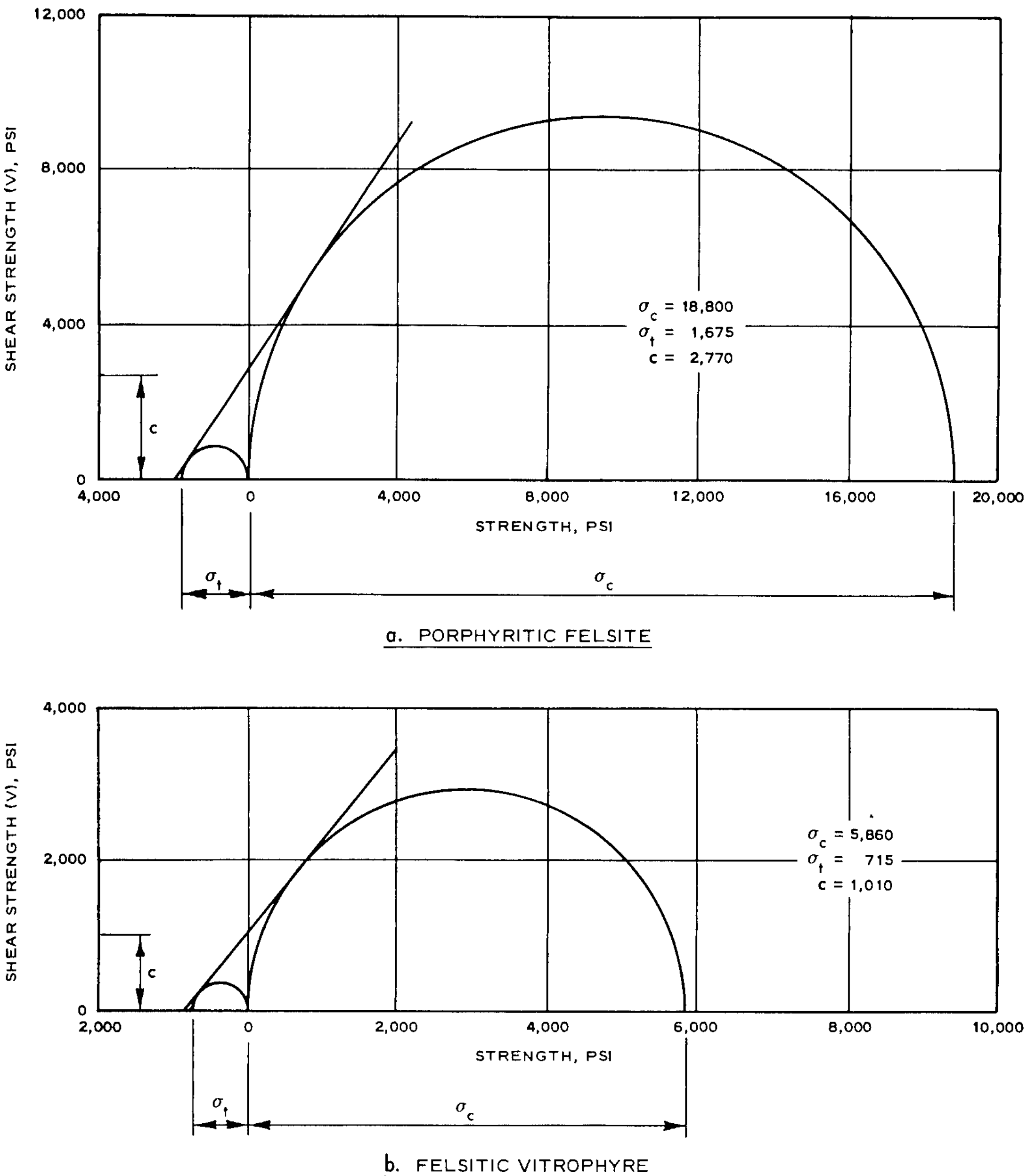


Figure 4 Mohr-circle analysis for shear strength determination; porphyritic felsite and felsitic vitrophyre.

REFERENCES

1. R. G. Wuerker; "The Shear Strength of Rocks"; Mining Engineering, October 1959, Vol 11, Pages 1022-1026; Unclassified.

2. C. H. Norris and others; "Structural Design for Dynamic Loads"; 1959; McGraw-Hill Book Company, Inc., New York, N. Y.; Unclassified.

3. Indraradan Shah; "Dynamic Shear Strength of Concrete Keys"; R-63-5, January 1963; Massachusetts Institute of Technology, Cambridge, Mass.; Unclassified.

DISTRIBUTION

LRL Internal Distribution	No. of Copies
Director's Office	
Information Department	2
R. Batzel	
J. Bell	
J. Carothers	
W. Decker	
S. Fernbach	
R. Goeckermann	
J. Gofman	
E. Goldberg	
J. Hadley	
W. Harford	
C. Haussmann	
R. Herbst	
G. Higgins	
A. Holzer	2
E. Hulse	
J. Kane	
J. Knox	2
J. Kury	
C. McDonald	
M. Nordyke	2
J. Rosengren	

Distribution List, cont'd.

	No. of Copies
B. Rubin	
D. Sewell	
P. Stevenson	2
H. Tewes	2
C. Van Atta	
G. Werth	
LRL Berkeley,	
R. K. Wakerling	
D. M. Wilkes	
E. Teller	
LRL Mercury,	
L. Crooks	
External Distribution,	
TID-4500, UC-35, Nuclear Explosions - Peaceful Applications	277
Department of Mines and Technical Surveys Canada	
D. J. Convey	2
Oil and Gas Conservation Board Canada	
G. W. Govier	2
U. S. Army Engineer Division, Lower Mississippi Valley Vicksburg, Mississippi	
U. S. Army Engineer District, Memphis Memphis, Tennessee	
U. S. Army Engineer District, New Orleans New Orleans, Louisiana	

Distribution List, cont'd.	No. of Copies
U. S. Army Engineer Waterways Experiment Station Vicksburg, Mississippi	75
U. S. Army Engineer District, St. Louis St. Louis, Missouri	
U. S. Army Engineer District, Vicksburg Vicksburg, Mississippi	
U. S. Army Engineer Division, Mediterranean APO, New York	
U. S. Army Liaison Detachment New York, New York	
U. S. Army Engineer District, GULF APO, New York	
U. S. Army Engineer Division, Missouri River Omaha, Nebraska	2
U. S. Army Engineer District, Kansas City Kansas City, Missouri	
U. S. Army Engineer District, Omaha Omaha, Nebraska	2
U. S. Army Engineer Division, New England Waltham, Massachusetts	
U. S. Army Engineer Division, North Atlantic New York, New York	
U. S. Army Engineer District, Baltimore Baltimore, Maryland	
U. S. Army Engineer District, New York New York, New York	
U. S. Army Engineer District, Norfolk Norfolk, Virginia	
U. S. Army Engineer District, Philadelphia Philadelphia, Pennsylvania	
U. S. Army Engineer Division, North Central Chicago, Illinois	
U. S. Army Engineer District, Buffalo Buffalo, New York	

Distribution List, cont'd. **No. of Copies**

U. S. Army Engineer District, Chicago
Chicago, Illinois

U. S. Army Engineer District, Detroit
Detroit, Michigan

U. S. Army Engineer District, Rock Island
Rock Island, Illinois

U. S. Army Engineer District, St. Paul
St. Paul, Minnesota

U. S. Army Engineer District, Lake Survey
Detroit, Michigan

U. S. Army Engineer Division, North Pacific
Portland, Oregon

U. S. Army Engineer District, Portland
Portland, Oregon

U. S. Army Engineer District, Alaska
Anchorage, Alaska

U. S. Army Engineer District, Seattle
Seattle, Washington

U. S. Army Engineer District, Walla Walla
Walla Walla, Washington

U. S. Army Engineer Division, Ohio River
Cincinnati, Ohio

U. S. Army Engineer District, Huntington
Huntington, West Virginia

U. S. Army Engineer District, Louisville
Louisville, Kentucky

U. S. Army Engineer District, Nashville
Nashville, Tennessee

U. S. Army Engineer District, Pittsburgh
Pittsburgh, Pennsylvania

U. S. Army Engineer Division, Pacific Ocean
Honolulu, Hawaii

U. S. Army Engineer District, Far East
APO, San Francisco, California

Distribution List, cont'd. **No. of Copies**

U. S. Army Engineer District, Honolulu
Honolulu, Hawaii

U. S. Army Engineer District, Okinawa
APO, San Francisco, California

U. S. Army Engineer Division, South Atlantic
Atlanta, Georgia

U. S. Army Engineer District, Canaveral
Merritt Island, Florida

U. S. Army Engineer District, Charleston
Charleston, South Carolina

U. S. Army Engineer District, Jacksonville
Jacksonville, Florida

U. S. Army Engineer District, Mobile
Mobile, Alabama

U. S. Army Engineer District, Savannah
Savannah, Georgia

U. S. Army Engineer District, Wilmington
Wilmington, North Carolina

U. S. Army Engineer Division, South Pacific
San Francisco, California

U. S. Army Engineer District, Los Angeles
Los Angeles, California

U. S. Army Engineer District, Sacramento
Sacramento, California

U. S. Army Engineer District, San Francisco
San Francisco, California

U. S. Army Engineer Division, Southwestern
Dallas, Texas

U. S. Army Engineer District, Albuquerque
Albuquerque, New Mexico

U. S. Army Engineer District, Fort Worth
Forth Worth, Texas

U. S. Army Engineer District, Galveston
Galveston, Texas

Distribution List, cont'd. **No. of Copies**

U. S. Army Engineer District, Little Rock
Lttle Rock, Arkansas

U. S. Army Engineer District, Tulsa
Tulsa, Oklahoma

U. S. Army Coastal Engineering Research Board
Washington, D. C.

Mississippi River Commission
Vicksburg, Mississippi

Rivers and Harbors, Boards of Engineers
Washington, D. C.

Corps of Engineers Ballistic Missile Construction Office
Norton Air Force Base, California

U. S. Army Engineer Center
Ft. Belvoir, Virginia

U. S. Army Engineer Reactors Group
Ft. Belvoir, Virginia

U. S. Army Engineer Training Center
Ft. Leonard Wood, Missouri

U. S. Army Engineer School
Ft. Belvoir, Virginia

U. S. Army Engineer Nuclear Cratering Group 74
Livermore, California